UNCLASSIFIED

(2)

AD-A214 864 RT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Research Laboratory of Electronics Massachusetts Institute of Technology 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) 77 Massachusetts Avenue Cambridge, MA 02139	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING / SPONSORING ORGANIZATION Office of Naval Research 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N00014-81-K-0742
8c. ADDRESS (City, State, and ZIP Code) Mathematical Sci. Div., Code 1111SP 800 N Quincy Street Arlington, VA 22217	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. 4119351 / TASK NO. / WORK UNIT ACCESSION NO

11. TITLE (Include Security Classification)

Knowledge Based Signal Processing

12. PERSONAL AUTHOR(S)

Alan V. Oppenheim

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 7-1-81 TO 9-30-89	11-17-89	

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Work by Alan V. Oppenheim and his collaborators is summarized here

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Mary Greene - RLE Contract Reports	22b. TELEPHONE (Include Area Code) (617) 258-5871 22c. OFFICE SYMBOL

DD Form 1473, JUN 86 Previous editions are obsolete. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED

OFFICE OF NAVAL RESEARCH

FINAL REPORT

for

1 JULY 1981 THROUGH 30 SEPTEMBER 1989

for

CONTRACT NO. N00014-81-K-0742

TASK NO. NR 049-506

SIGNAL PROCESSING

ALAN V. OPPENHEIM, PRINCIPAL INVESTIGATOR

RESEARCH LABORATORY OF ELECTRONICS

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

CAMBRIDGE, MASSACHUSETTS 02139

I. Introduction

The research carried out under this contract is categorized under seven major topic areas. In all of these areas, the work and results have been thoroughly documented through the publication of technical reports, conference papers and journal articles. In Section II, a brief summary of the work in each of these topic areas is given. In Section III is a complete listing of all of the publications based on work supported in whole or in part under this contract. One publication has been selected as an example of each of the major topic areas, although it is not necessarily representative of the broad scope of the work under this topic. This set of papers is contained in the Appendix. Each of the publications selected has had, or is expected to have, a significant impact in the research community. Section IV is a complete list of technical reports based on work supported in whole or in part under this contract. Section V is a summary of honors and awards received during the life of this contract.

II. Topic Summaries

Symbolic Signal Processing

The research in this area focussed on the development of symbolic representations of signals and the use of symbolic manipulation to provide an environment for signal processing system design. It also developed innovative tools and techniques for combining both numerical and symbolic technologies in signal processing systems. Work reported under this aspect of the project is generally considered to be the first demonstration of a symbolic signal processing environment for algorithm design. Under this project, two software packages were developed. The first, SPLICE (Signal Processing Language and Interactive Computing Environment), was provided to a large number of DARPA-supported research groups. The second, E-SPLICE, was the first demonstration of the use of symbolic manipulation of signal processing expressions to develop new algorithms.

Signal Reconstruction

In this aspect of the research, a number of new and potentially very important results were developed on the reconstruction of signals from partial information plus constraints. For example, it was shown that, both theoretically and practically, a finite length signal could be exactly recovered from only its Fourier transform phase or magnitude. Furthermore, it was shown and demonstrated that two-dimensional signals such as images could be reconstructed from a single set of threshold crossings if the signals are bandlimited. A variety of iterative algorithms were also developed for signal reconstruction and parameter identification based on noisy and incomplete data.

Spectral Analysis

Much of our work in this topic area was concerned with the development of methods for multidimensional spectral estimation. In particular, a new method of maximum likelihood spectral estimation was developed but with significantly better resolution than prior methods. We also developed a computationally attractive algorithm to solve the two-dimensional maximum entropy spectral estimation problem. In other work, a number of fast and efficient algorithms for maximum entropy spectral analysis were developed.

Acoustic And Sonar Signal Processing

Effort under this aspect of the project consisted of joint work with the Woods Hole Oceanographic Institution on the development of new signal processing techniques for measurement of ocean characteristics and the ocean bottom reflection coefficients. A new and efficient algorithm for the determination of the Hankel transform was developed and applied to ocean acoustics measurements with considerable success. Also, under this phase of the work, a

new scheme for multiple-beam sonar imaging was developed. A particularly efficient implementation of one aspect of the associated signal processing was found using the symbolic signal processing design environment developed under this contract.

Speech Processing

A principal accomplishment under this aspect of the research was the development of a new model for speech incorporating a mixed voiced-unvoiced multiband spectral representation. This model was used to develop an extremely high-quality speech compression system which subsequently underwent extensive testing by the Deparment of Defense.

Image and Video Processing

Much of the work in this area involved motion estimation and compensation for video and scene analyis for images. In particular, several new algorithms were developed for motion estimation and applied to video compression for low data rate video conferencing.

Signal Modelling and Short-Time Fourier Analysis

Signal modelling through parametric representations and through time dependent or short time Fourier analysis is important in a variety of signal processing contexts. In our work in this area under this contract, we developed a theoretical basis for signal representation and reconstruction through short-time Fourier analysis with and without the incorporation of phase.

III. Publications

1. Thomas F. Quatieri and Alan V. Oppenheim, "Iterative Techniques for Minimum Phase Signal Reconstruction from Phase or Magnitude", IEEE Trans. on Acoustics, Speech, and Signal Processing, Vol. ASSP-29, No. 6, pp. 1187-1193, December 1981.

2. Jae S. Lim and Naveed A. Malik, "Maximum Entropy Power Spectrum Estimation of Signals with Missing Correlation Points", IEEE Trans. on Acoustics, Speech, and Signal Processing, Correspondence, Vol. ASSP-29, No. 6, pp. 1215-1217, December 1981.

3. S. Hamid Nawab, "Signal Estimation from Short-Time Spectral Magnitude", RLE Technical Report No. 494, Research Laboratory of Electronics, M.I.T., Cambridge, MA, May 1982.

4. Andrew L. Kurkjian, "The Estimation of the Cylindrical Wave Reflection Coefficient", RLE Technical Report No. 495, Research Laboratory of Electronics, M.I.T., Cambridge, MA, July 1982.

5. Gary E. Kopec, Alan V. Oppenheim, and Randall Davis, "Knowledge-Based Signal Processing", Trends & Perspectives in Signal Processing, Vol. 2, No. 3, pp. 1-6, July 1982.

6. Patrick Van Hove, Jae S. Lim, and A.V. Oppenheim, "Signal Reconstruction from Fourier Transform Amplitude", Proceedings, Society of Photo-Optical Instrumentation Engineers Conference, San Diego, CA, August 22-27, 1982, Vol. 359, pp. 214-225, 1982.

7. Bruce R. Musicus, "Iterative Algorithms for Optimal Signal Reconstruction and Parameter Identification Given Noisy and Incomplete Data", RLE Technical Report No. 496, Research Laboratory of Electronics, M.I.T., Cambridge, MA, September 1982.

8. Naveed A. Malik and Jae S. Lim, "Properties of Two-Dimensional Maximum Entropy Power Spectrum Estimates", IEEE Trans. on Acoustics, Speech, and Signal Processing, Vol. ASSP-30, No. 5, pp. 788-798, October 1982.

9. George V. Frisk, Douglas R. Mook, James A. Doutt, Earl E. Hays, and Alan V. Oppenheim, "The Application to Real Data of a Technique for Measuring the Plane-Wave Reflection Coefficient of the Ocean Bottom", abstract, Journal of the Acoustical Society of America, Program of 104th Meeting, Orlando, FL, November 8-12, 1982, p. S97.

10. J.S. Lim, J. Anderson, and C. Searle, "Signal Reconstruction from Cosine Transform Magnitude", IEEE Proceedings, Correspondence, Vol. 70, No. 12, pp. 1460-1462, December 1982.

11. Douglas R. Mook, "The Numerical Synthesis and Inversion of Acoustic Fields Using the Hankel Transform with Application to the Estimation of the Plane Wave Reflection Coefficient of the Ocean Bottom", RLE Technical Report No. 497, Research Laboratory of Electronics, M.I.T., Cambridge, MA, January 1983.

12. T.F. Quatieri, S.H. Nawab, and J.S. Lim, "Frequency Sampling of the Short-Time Fourier Transform Magnitude", summary of presentation, Topical Meeting on Signal Recovery and Synthesis with Incomplete Information and Partial Constraints, Optical Society of America, Incline Village, Nevada, January 12-14, 1983, pp. ThA9-1 - ThA9-4.

13. A.V. Oppenheim and J.S. Lim, "Signal Reconstruction from Partial Fourier Domain Information", summary of presentation, Topical Meeting on Signal Recovery and Synthesis with Incomplete Information and Partial Constraints, Optical Society of America, Incline Village, Nevada, January 12-14, 1983, pp. ThA12-1 - ThA12-4.

14. Patrick L. Van Hove, J.S. Lim, and A.V. Oppenheim, "Signal Reconstruction from Fourier Transform Amplitude", summary of presentation, Topical Meeting on Signal Recovery and Synthesis with Incomplete Information and Partial Constraints, Optical Society of America, Incline Village, Nevada, January 12-14, 1983, pp. ThA15-1 - ThA15-4.

15. Jae S. Lim and Farid U. Dowla, "A New Algorithm for High-Resolution Two-Dimensional Spectral Estimation", IEEE Proceedings, Correspondence, Vol. 71, pp. 284-285, February 1983.

16. Yen-ta Li and Andrew L. Kurkjian, "Arrival Time Determination using Iterative Signal Reconstruction from the Phase of the Cross Spectrum", IEEE Trans. on Acoustics, Speech, and Signal Processing, Correspondence, Vol. ASSP-31, No. 2, pp. 502-504, April 1983.

17. Bruce R. Musicus, "Iterative Algorithms for Optimal Signal Reconstruction and Parameter Identification Given Noisy and Incomplete Data", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Boston, MA, April 14-16, 1983, Vol. 1, pp. 235-238.

18. Evangelos E. Milios and Alan V. Oppenheim, "The Phase-Only Version of the LPC Residual in Speech Coding", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Boston, MA, April 14-16, 1983, Vol. 2, pp. 797-799.

19. S. Hamid Nawab, Thomas F. Quatieri, and Jae S. Lim, "Algorithms for Signal Reconstruction from Short-Time Fourier Transform Magnitude", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Boston, MA, April 14-16, 1983, Vol. 2, pp. 800-803.

20. Daniel W. Griffin and J.S. Lim, "Signal Estimation from Modified Short-Time Fourier Transform", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Boston, MA, April 14-16, 1983, Vol. 2, pp. 804-807.

21. Jae S. Lim and Farid U. Dowla, "Improved Maximum Likelihood Method for Two-Dimensional Spectral Estimation", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Boston, MA, April 14-16, 1983, Vol. 2, pp. 851-854.

22. Cengiz Esmersoy and J.S. Lim, "Subjective Evaluation of a PCM Speech Coding System with Quantization Noise Reduction", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Boston, MA, April 14-16, 1983, Vol. 3, pp. 1137-1140.

23. Howard C. Reeve, III, and Jae S. Lim, "Reduction of Blocking Effect in Image Coding", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Boston, MA, April 14-16, 1983, Vol. 3, pp. 1212-1215.

24. W. Dove, C. Myers, A. Oppenheim, R. Davis, and G. Kopec, "Knowledge-Based Pitch Detection", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Boston, MA, April 14-16, 1983, Vol. 3, pp. 1348-1351.

25. M.G. Hall, A.V. Oppenheim, and A.S. Willsky, "Time-Varying Parametric Modeling of Speech", Signal Processing, Vol. 5, No. 3, pp. 267-285, May 1983.

26. David Izraelevitz, "Overspecified Normal Equations for Spectral Estimation", RLE Technical Report No. 498, Research Laboratory of Electronics, M.I.T., Cambridge, MA, June 1983.

27. C.Y. Espy and J.S. Lim, "Effects of Additive Noise on Signal Reconstruction From Fourier Transform Phase", IEEE Trans. on Acoustics, Speech, and Signal Processing, Vol. ASSP-31, No. 4, pp. 894-898, August 1983.

28. Andrew L. Kurkjian and Shu-Kong Chang, "Arrays of Synthetic Acoustic Well Logging Waveforms: Computation and Source Design", IEEE Trans. on Acoustics, Speech, and Signal Processing, Vol. ASSP-31, No. 4, pp. 946-955, August 1983.

29. Douglas R. Mook, "An Algorithm for the Numerical Evaluation of the Hankel and Abel Transforms", IEEE Trans. on Acoustics, Speech, and Signal Processing, Vol. ASSP-31, No. 4, pp. 979-985, August 1983.

30. H. Nawab, T.F. Quatieri, and J.S. Lim, "Signal Reconstruction from Short-Time Fourier Transform Magnitude", IEEE Trans. on Acoustics, Speech and Signal Processing, Vol. ASSP-31, No. 4, pp. 986-998, August 1983.

31. Patrick L. Van Hove, Monson H. Hayes, Jae S. Lim, and Alan V. Oppenheim, "Signal Reconstruction from Signed Fourier Transform Magnitude", IEEE Trans. on Acoustics, Speech, and Signal Processing, Vol. ASSP-31, No. 5, pp. 1286-1293, October 1983.

32. David Izraelevitz and Jae S. Lim, "Spectral Characteristics of the Overdetermined Normal Equation Method for Spectral Estimation", ASSP Spectrum Estimation Workshop II, Tampa, FL, November 10-11, 1983, pp. 49-54.

33. Alan V. Oppenheim, Jae S. Lim, and Susan R. Curtis, "Signal Synthesis and Reconstruction from Partial Fourier Domain Information", Journal of the Optical Society of America, Vol. 73, No. 11, pp. 1413-1420, November 1983.

34. T.F. Quatieri, S.H. Nawab, and J.S. Lim, "Frequency Sampling of the Short-Time Fourier Transform Magnitude for Signal Reconstruction", Journal of the Optical Society of America, Vol. 73, No. 11, pp. 1523-1526, November 1983.

35. Philip Chan and Jae S. Lim, "One-Dimensional Processing for Adaptive Image Restoration", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, San Diego, CA, March 19-21, 1984, pp. 37.3.1-37.3.4.

36. Susan R. Curtis, Jae S. Lim, and Alan V. Oppenheim, "Signal Reconstruction from One Bit of Fourier Transform Phase", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, San Diego, CA, March 19-21, 1984, pp. 12A.5.1-12A.5.4.

37. Farid U. Dowla and Jae S. Lim, "Relationship Between Maximum-Likelihood Method & Autoregressive Modeling in Multi-Dimensional Power Spectrum Estimation", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, San Diego, CA, March 19-21, 1984, pp. 5.3.1-5.3.4.

38. Daniel W. Griffin, Douglas S. Deadrick, and Jae S. Lim, "Speech Synthesis from Short-Time Fourier Transform Magnitude and its Application to Speech Processing", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, San Diego, CA, March 19-21, 1984, pp. 2.4.1-2.4.4.

39. Evangelos E. Milios, "Fast Sequential Least-Squares Processing", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, San Diego, CA, March 19-21, 1984, pp. 22.6.1-22.6.4.

40. Cory Myers, A.V. Oppenheim, Randall Davis, and Webster P. Dove, "Knowledge-Based Speech Analysis and Enhancement", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, San Diego, CA, March 19-21, 1984, pp. 39A.4.1-39A.4.4.

41. Daniel W. Griffin and Jae S. Lim, "Signal Estimation from Modified Short-Time Fourier Transform", IEEE Trans. on Acoustics, Speech, and Signal Processing, Vol. ASSP-32, No. 2, pp. 236-243, April 1984.

42. Susan R. Curtis, Jae S. Lim, and Alan V. Oppenheim, "Signal Reconstruction from Fourier Transform Sign Information", RLE Technical Report No. 500, Research Laboratory of Electronics, M.I.T., Cambridge, MA, May 1984.

43. Philip Chan, "One-Dimensional Processing for Adaptive Image Restoration", RLE Technical Report No. 501, Research Laboratory of Electronics, M.I.T., Cambridge, MA, June 1984.

44. William A. Harrison, "Speech Enhancement using Multiple Microphones", S.M. and E.E. Thesis, June 1984.

45. Douglas R. Mook, George V. Frisk, and Alan V. Oppenheim, "A Hybrid Numerical/Analytic Technique for the Computation of Wave Fields in Stratified Media Based on the Hankel Transform", Journal of the Acoustical Society of America, Vol. 76, No. 1, pp. 222-243, July 1984.

46. Thrasyvoulos N. Pappas and Jae S. Lim, "Estimation of Coronary Artery Boundaries in Angiograms", Proceedings, Society of Photo-Optical Instrumentation Engineers Conference, San Diego, CA, August 21-24, 1984, Vol. 504, pp. 312-321.

47. D.W. Griffin and J.S. Lim, "A New Pitch Detection Algorithm", Proceedings, IEEE International Conference on Digital Signal Processing, Florance, Italy, September 5-8, 1984, pp. 395-399.

48. Daniel W. Griffin and Jae S. Lim, "A Speech Spectral Analysis/Synthesis System", Proceedings, 1984 Digital Signal Processing Workshop, Chatham, MA, October 8-10, 1984, pp. 5.1.1-5.1.2.

49. Cory Myers and Webster Dove, "Knowledge-Based Speech Processing", Proceedings, 1984 Digital Signal Processing Workshop, Chatham, MA, October 8-10, 1984, pp. 4.5.1-4.5.2.

50. Farid U. Dowla and Jae S. Lim, "Relationship Between Maximum-Likelihood Method & Autoregressive Modeling in Multi-Dimensional Power Spectrum Estimation", IEEE Trans. on Acoustics, Speech, and Signal Processing, Correspondence, Vol. ASSP-32, No. 5, pp. 1083-1087, October 1984.

51. W.P. Dove, C. Myers, and E.E. Milios, "An Object-Oriented Signal Processing Environment: The Knowledge-Based Signal Processing Package", RLE Technical Report No. 502, Research Laboratory of Electronics, M.I.T., Cambridge, MA, October 1984.

52. C.J. Kuo, B.C. Levy, and Bruce R. Musicus, "The Specification and Verification of Systolic Wave Algorithms", Workshop on VLSI Signal Processing, University of Southern California, November 27-29, 1984.

53. Philip Chan and Jae S. Lim, "One-Dimensional Processing for Adaptive Image Restoration", IEEE Trans. on Acoustics, Speech, and Signal Processing, Vol. ASSP-33, No. 1, pp. 117-125, February 1985.

54. Farid U. Dowla and Jae S. Lim, "Resolution Property of the Improved Maximum Likelihood Method", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Tampa, FL, March 26-29, 1985, Vol. 2, pp. 820-822.

55. D.W. Griffin and Jae S. Lim, "A New Model-Based Speech Analysis/Synthesis System", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Tampa, FL, March 26-29, 1985, Vol. 2, pp. 513-516.

56. Dennis Martinez and Jae S. Lim, "Implicit Motion Compensated Noise Reduction of Motion Video Scenes", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Tampa, FL, March 26-29, 1985, Vol. 1, pp. 375-378.

57. Evangelos E. Milios and Hamid Nawab, "Interpretation-Guided Signal Processing via Protocol Analysis", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Tampa, FL, March 26-29, 1985, Vol. 4, pp. 1660-1663.

58. Susan R. Curtis, Alan V. Oppenheim, and Jae S. Lim, "Reconstruction of Two-Dimensional Signals from Threshold Crossings", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Tampa, FL, March 26-29, 1985, Vol. 3, pp. 1057-1060.

59. David Izraelevitz and Jae S. Lim, "Properties of the Overdetermined Normal Equation Method for Spectral Estimation when Applied to Sinusoids in Noise", IEEE Trans. on ASSP, Vol. ASSP-33, No. 2, pp. 406-412, April 1985.

60. Susan R. Curtis, "Reconstruction of Multidimensional Signals from Zero Crossings", Ph.D. Thesis, RLE Technical Report No. 509, Research Laboratory of Electronics, M.I.T., Cambridge, MA, June 1985.

61. Susan R. Curtis, Alan V. Oppenheim, and Jae S. Lim, "Signal Reconstruction from Fourier Transform Sign Information", IEEE Trans. on ASSP, Vol. ASSP-33, No. 3, pp. 643-657, June 1985.

62. Bruce R. Musicus, "Fast MLM Power Spectrum Estimation from Uniformly Spaced Correlations", IEEE Trans. on ASSP, Vol. ASSP-33, No. 4, pp. 1333-1335, October 1985.

63. Bruce R. Musicus and Allan M. Kabel, "Maximum Entropy Pole-Zero Estimation", RLE Technical Report No. 510, Research Laboratory of Electronics, M.I.T., Cambridge, MA, August 1985.

64. Avideh Zakhor, "Error Properties of Hartley Transform Algorithms", RLE Technical Report No. 511, Research Laboratory of Electronics, M.I.T., Cambridge, MA, October 1985.

65. David Izraelevitz, "Some Results on the Time-Frequency Sampling of the Short-Time Fourier Transform Magnitude", IEEE Trans. on ASSP, Vol. ASSP-33, No. 6, December 1985.

66. Anthony J. Silva, "Reconstruction of Undersampled Periodic Signals", RLE Technical Report No. 514, Research Laboratory of Electronics, M.I.T., Cambridge, MA, January 1986.

67. Susan R. Curtis and A.V. Oppenheim, "Reconstruction of Multidimensional Signals from Zero Crossings", Proceedings, Optical Society of America, Topical Meeting on Signal Recovery & Synthesis II, Honolulu, Hawaii, April 2-4, 1986, pp. 126-129.

68. Patrick Van Hove, "Reconstruction of Axisymmetric Objects from One Silhouette", Proceedings, Optical Society of America, Topical Meeting on Signal Recovery & Synthesis II, Honolulu, Hawaii, April 2-4, 1986, pp. 87-90.

69. Michael S. Wengrovitz, A.V. Oppenheim, and George V. Frisk, "Reconstruction of a Complex-Valued Field Using the Hilbert-Hankel Transform", Proceedings, Optical Society of America, Topical Meeting on Signal Recovery & Synthesis II, Honolulu, Hawaii, April 2-4, 1986, pp. 140-143.

70. Daniel W. Griffin and Jae S. Lim, "A High Quality 9.6 kbps Speech Coding System", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Tokyo, Japan, April 8-11, 1986.

71. Bruce R. Musicus and Allan M. Kabel, "Maximum Entropy Pole-Zero Estimation", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Tokyo, Japan, April 8-11, 1986, pp. 1389-1392.

72. Cory Myers, "On the Use of Linear Programming for Spectral Estimation", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Tokyo, Japan, April 8-11, 1986, pp. 189-192.

73. Hamid Nawab, Victor Lesser, and Evangelos Milios, "Conceptual Diagnosis of Signal Processing Systems", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Tokyo, Japan, April 8-11, 1986, pp. 2911-2914.

74. Michael S. Wengrovitz, Alan V. Oppenheim, and George V. Frisk, "Reconstruction of Propagating Complex Wave Fields Using the Hilbert-Hankel Transform", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Tokyo, Japan, April 8-11, 1986, pp. 2875-2878.

75. Evangelos E. Milios, "Signal Processing and Interpretation using Multilevel Signal Abstractions", RLE Technical Report No. 516, Research Laboratory of Electronics, M.I.T., Cambridge, MA, June 1986.

76. David Izraelevitz, "Reconstruction of Two-Dimensional Signals from the Fourier Transform Magnitude", RLE Technical Report No. 517, Research Laboratory of Electronics, M.I.T., Cambridge, MA, June 1986.

77. Webster P. Dove, "Knowledge-Based Pitch Detection", RLE Technical Report No. 518, Research Laboratory of Electronics, M.I.T., Cambridge, MA, June 1986.

78. Bruce R. Musicus and Rodney W. Johnson, "Multichannel Minimum Cross-Entropy Spectral Analysis", IEEE Trans. on ASSP, Vol. ASSP-34, pp. 554-564, June 1986.

79. Bruce R. Musicus, "A Comment on 'Dice, Entropy, and Likelihood' by B. Roy Frieden", Proceedings of the IEEE, Vol. 74, pp. 762-763, June 1986.

80. Cory S. Myers, "Signal Representation for Symbolic and Numerical Processing", RLE Technical Report No. 521, Research Laboratory of Electronics, M.I.T., Cambridge, MA, August 1986.

81. Avideh Zakhor and David Izraelevitz, "A Note on the Sampling of Zero-Crossings of Two-Dimensional Signals", Proceedings of the IEEE, Correspondence, Vol. 74, No. 9, pp. 1285-1287, September 1986.

82. Michele Covell and Jae Lim, "Low data-rate video conferencing", SPIE Proceedings, SPIE Vol. 707-Visual Communications and Image Processing, pp. 75-82, September 1986.

83. Patrick L. Van Hove, "Silhouette-Slice Theorems", RLE Technical Report No. 522, Research Laboratory of Electronics, M.I.T., Cambridge, MA, September 1986.

84. Webster P. Dove and Cory S. Myers, "Signal Representation and Manipulation in Computers", Digital Signal Processing Workshop, Chatham, MA, October 19-22, 1986.

85. Daniel W. Griffin and Jae S. Lim, "A High Quality 8 KBPS Speech Coding System", Digital Signal Processing Workshop, Chatham, MA, October 19-22, 1986.

86. Douglas R. Mook, S. Lang, Tae Joo, Webster P. Dove, and J. Smith, "A KBSP Approach to Sensor Fusion and Situation Assessment", Digital Signal Processing Workshop, Chatham, MA, October 19-22, 1986.

87. Anthony J. Silva and Alan V. Oppenheim, "Reconstruction of Undersampled Periodic Signals", Digital Signal Processing Workshop, Chatham, MA, October 19-22, 1986.

88. Meir Feder, "Maximum Entropy as a Special Case of the Minimum Description Length Criterion", IEEE Trans. on Information Theory, Correspondence, Vol. IT-32, No. 6, pp. 847-849, November 1986.

89. Susan R. Curtis and Alan V. Oppenheim, "Reconstruction of Multidimensional Signals from Zero Crossings", Journal of the Optical Society of America (JOSA A) Special Issue on Signal Recovery and Synthesis II, Vol. 4, No. 1, pp. 221-231, January 1987.

90. Michael S. Wengrovitz, Alan V. Oppenheim, and George V. Frisk, "Reconstruction of a Complex-Valued Field Using the Hilbert-Hankel Transform", Journal of the Optical Society of America, Vol. 4, No. 1, pp. 247-266, January 1987.

91. Daniel W. Griffin, "Multi-Band Excitation Vocoder", RLE Technical Report No. 524, Research Laboratory of Electronics, M.I.T., Cambridge, MA, February 1987.

92. Thrasyvoulos N. Pappas, "Estimation of Coronary Artery Dimensions in Angiograms", RLE Technical Report No. 528, Research Laboratory of Electronics, M.I.T., Cambridge, MA, April 1987.

93. David Izraelevitz and Jae S. Lim, "A New Direct Algorithm for Image Reconstruction from Fourier Transform Magnitude", IEEE Trans. on ASSP, Vol. ASSP-35, No. 4, pp. 511-519, April 1987.

94. Meir Feder, Alan V. Oppenheim, and Ehud Weinstein, "Methods for Noise Cancellation Based On The EM Algorithm", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Dallas, Texas, April 6-9, 1987.

95. Hong Jeong and Bruce R. Musicus, "Mask Extraction from Optical Images of VLSI Circuits", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Dallas,Texas, April 6-9, 1987, pp. 602-605.

96. Bruce R. Musicus and G.N.S. Prasanna, "A Small 16x16 Cellular Array for Image Processing", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Dallas, Texas, April 6-9, 1987.

97. Cory Myers, "Symbolic Representation and Manipulation of Signals", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Dallas, Texas, April 6-9, 1987, Vol. 4, pp. 2400-2403.

98. Susan R. Curtis, Shlomo Shitz, and Alan V. Oppenheim, "Reconstruction of Nonperiodic Two-Dimensional Signals from Zero Crossings", IEEE Trans. on ASSP, Correspondence, Vol. ASSP-35, No. 6, pp. 890-893, June 1987.

99. Dennis Michael Martinez, "Model-Based Motion Estimation and its Application to Restoration and Interpolation of Motion Pictures", RLE Technical Report No. 530, Research Laboratory of Electronics, M.I.T., Cambridge, MA, June 1987.

100. C.-C. Jay Kuo, Bernard C. Levy, and Bruce R. Musicus, "A Local Relaxation Method for Solving Elliptic PDE's on Mesh-Connected Arrays", SIAM Journal on Scientific and Statistical Computing, Vol. 8, No. 4, July 1987.

101. C.-C. Jay Kuo, "Discretization and Solution of Elliptic PDEs: A Transform Domain Approach", published by the Laboratory for Information and Decision Systems, M.I.T., Cambridge, MA, August 1987.

102. Meir Feder, "Statistical Signal Processing using a class of Iterative Estimation Algorithms", RLE Technical Report No. 532, Research Laboratory of Electronics, M.I.T., Cambridge, MA, January 1988.

103. W. Song and Bruce R. Musicus, "A Fault-Tolerant Architecture for a Parallel Digital Signal Processing Machine", Proceedings, 1987 International Conference on Computer and Circuit Design, Rye, New York, October 1987.

104. Avideh Zakhor and Alan V. Oppenheim, "Quantization Errors in the Computation of the Discrete Hartley Transform", IEEE Trans. on ASSP, Vol. ASSP-35, No. 11, pp. 1592-1602, November 1987.

105. Avideh Zakhor, "Reconstruction of Multidimensional Signals from Multiple Level Threshold Crossings", RLE Technical Report No. 534, Research Laboratory of Electronics, M.I.T., Cambridge, MA, January 1988.

106. Meir Feder and Ehud Weinstein, "Parameter Estimation of Superimposed Signals Using the EM Algorithm", IEEE Trans. on ASSP, Vol. 36, No. 4, pp. 477-489, April 1988.

107. Meir Feder, Ehud Weinstein, and Alan V. Oppenheim, "A New Class of Sequential and Adaptive Algorithms with Application to Noise Cancellation", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, New York, New York, April 11-14, 1988, pp. 557-560.

108. Daniel J. Harasty and Alan V. Oppenheim, "Television Signal Deghosting by Noncausal Recursive Filtering", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, New York, New York, April 11-14, 1988, pp. 1778-1781.

109. John Hardwick and Jae S. Lim, "A 4.8 Kbps Multi-Band Excitation Speech Coder", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, New York, New York, April 11-14, 1988, pp. 374-377.

110. Tae H. Joo and Alan V. Oppenheim, "Effects of FFT coefficient quantization on sinusoidal signal detection", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, New York, New York, April 11-14, 1988, pp. 1818-1821.

111. Avideh Zakhor and Alan V. Oppenheim, "Sampling schemes for reconstruction of multidimensional signals from multiple level threshold crossings", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, New York, New York, April 11-14, 1988, pp. 721-724.

112. Daniel W. Griffin and Jae S. Lim, "Multiband Excitation Vocoder", IEEE Trans. on ASSP, Vol. ASSP-36, No. 8, pp 1223-1235, August 1988.

113. Thrasyvoulos N. Pappas and Jae S. Lim, "A New Method for Estimation of Coronary Artery Dimensions in Angiograms", IEEE Trans. on ASSP, Vol. ASSP-36, No. 9, September 1988.

114. Meir Feder, Alan V. Oppenheim, and Ehud Weinstein, "Maximum Likelihood Noise Cancellation Using the EM Algorithm", IEEE Trans. on ASSP, Vol. ASSP-37, No. 2, February 1989.

115. John C. Hardwick and Jae S. Lim, "The Dual Excitation Speech Model", Proceedings, Second ASSP Mini Conference, IEEE Central New England Chapter, Weston, MA, May 1989.

116. Matthew M. Bace and Jae S. Lim, "An Iterative Method for Designing Separable Wiener Filters", Proceedings, Second ASSP Mini Conference, IEEE Central New England Chapter, Weston, MA, May 1989.

117. Meir Feder and Jules Jaffe, "Limited-Angle Reconstruction from Noisy Data Using Clustering of the Solution Space", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Glasgow, Scotland, May 23-26, 1989.

118. Mordechai Segal and Ehud Weinstein, "Spatial and Spectral Parameter Estimation of Multiple Source Signals", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Glasgow, Scotland, May 23-26, 1989.

119. Ehud Weinstein and Meir Feder,"Sequential Algorithms Based on Kullback-Liebler Information Measure and their Application to FIR System Identification", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Glasgow, Scotland, May 23-26, 1989.

120. Jules S. Jaffe and John M. Richardson, "Code-Division Multiple Beam Imaging", Proceedings, Oceans '89 Conference, Seattle, Washington, September 17-21, 1989.

IV. Technical Reports

1. Syed Hamid Nawab, "Signal Estimation from Short-time Spectral Magnitude", RLE Technical Report No. 494, May 1982.

2. Andrew Loris Kurkjian, "The Estimation of the Cylindrical Wave Reflection Coefficient", RLE Technical Report No. 495, July 1982.

3. Bruce Ronald Musicus, "Iterative Algorithms for Optimal Signal Reconstruction and Parameter Identification Given Noisy and Incomplete Data", RLE Technical Report No. 496, September 1982.

4. Douglas R. Mook, "The Numerical Synthesis and Inversion of Acoustic Fields Using the Hankel Transform with Application to the Estimation of the Plane Wave Reflection Coefficient of the Ocean Bottom", RLE Technical Report No. 497, January 1983.

5. S.R. Curtis, J.S. Lim, and A.V. Oppenheim, "Signal Reconstruction from Fourier Transform Sign Information", RLE Technical Report No. 500, May 1984.

6. Philip Chan, "One-Dimensional Processing for Adaptive Image Restoration", RLE Technical Report No. 501, June 1984.

7. Webster P. Dove, Cory Myers, and Evangelos E. Milios, "An Object-Oriented Signal Processing Environment: The Knowledge-Based Signal Processing Package", RLE Technical Report No. 502, October 1984.

8. Susan R. Curtis, "Reconstruction of Multidimensional Signals from Zero Crossings", RLE Technical Report No. 509, June 1985.

9. Bruce R. Musicus and Allan M. Kabel, "Maximum Entropy Pole-Zero Estimation", RLE Technical Report No. 510, August 1985.

10. Avideh Zakhor, "Error Properties of Hartley Transform Algorithms", RLE Technical Report No. 511, October 1985.

11. Anthony J. Silva, "Reconstruction of Undersampled Periodic Signals", RLE Technical Report No. 514, January 1986.

12. Evangelos E. Milios, "Signal Processing and Interpretation using Multilevel Signal Abstractions", RLE Technical Report No. 516, June 1986.

13. David Izraelevitz, "Reconstruction of Two-Dimensional Signals from the Fourier Transform Magnitude", RLE Technical Report No. 517, June 1986.

14. Webster P. Dove, "Knowledge-Based Pitch Detection", RLE Technical Report No. 518, June 1986.

15. Cory S. Myers, "Signal Representation for Symbolic and Numerical Processing", RLE Technical Report No. 521, August 1986.

16. Patrick L. Van Hove, "Silhouette-Slice Theorems", RLE Technical Report No. 522, September 1986.

17. Daniel W. Griffin, "Multi-Band Excitation Vocoder", RLE Technical Report No. 524, March 1987.

18. Thrasyvoulos N. Pappas, "Estimation of Coronary Artery Dimensions from Angiograms", RLE Technical Report No. 528, April 1987.

19. Dennis Michael Martinez, "Model-Based Motion Estimation and its Application to Restoration and Interpolation of Motion Pictures", RLE Technical Report No. 530, June 1987.

20. Meir Feder, "Statistical Signal Processing using a class of Iterative Estimation Algorithms", RLE Technical Report No. 532, September 1987.

21. Avideh Zakhor, "Reconstruction of Multidimensional Signals from Multiple Level Threshold Crossings", RLE Technical Report No. 534, January 1988.

V. Honors and Awards

Jae S. Lim

1984	1984 Graduate Student Council Teaching Award
1984	1984 Harold E. Edgerton Faculty Achievement Award
1985	1985 IEEE ASSP Society Senior Award
1985	1985 ASSP Senior Paper Award, "Signal Estimation from Modified Short-Time Fourier Transform", (with **Daniel W. Griffin**).
1985	IEEE Fellow
1989	Became full Professor in the Department of Electrical Engineering and Computer Science, M.I.T.

Bruce R. Musicus

1982-1983	Became Assistant Professor in the Department of Electrical Engineering and Computer Science, M.I.T.
1983-1985	Class of 1956 Career Development Assistant Professor
1986-Present	Rockwell International Career Development Assistant Professor

Cory S. Myers

1984	Centennial Young Engineers Award, IEEE Society of Acoustics, Speech and Signal Processing

Alan V. Oppenheim

1981	Graduate Student Council Teaching Award, Department of Electrical Engineering and Computer Science, M.I.T.
1984	IEEE Centennial Medal, Acoustics, Speech and Signal Processing Society, "in recognition of your work for and contributions to our Society and its areas of interest".
1987	Elected to membership in the National Academy of Engineering.
1988	IEEE 1988 Education Medal, "For leadership in engineering education through teaching, textbooks, and video tape series in digital signal processing".

APPENDIX

1. Naveed A. Malik and Jae S. Lim, "Properties of Two-Dimensional Maximum Entropy Power Spectrum Estimates", IEEE Trans. on ASSP, Vol. ASSP-30, No. 5, pp. 788-798, October 1982.

2. H. Nawab, T.F. Quatieri, and J.S. Lim, "Signal Reconstruction from Short-Time Fourier Transform Magnitude", IEEE Trans. on ASSP, Vol. ASSP-31, No. 4, pp. 986-998, August 1983.

3. Daniel W. Griffin and Jae S. Lim, "Signal Estimation from Modified Short-Time Fourier Transform", IEEE Trans. on ASSP, Vol. ASSP-32, No. 2, pp. 236-243, April 1984.

4. Douglas R. Mook, George V. Frisk, and Alan V. Oppenheim, "A Hybrid Numerical/Analytic Technique for the Computation of Wave Fields in Stratified Media Based on the Hankel Transform", Journal of the Acoustical Society of America, Vol. 76, No. 1, pp. 222-243, July 1984.

5. W.P. Dove, C. Myers, and E.E. Milios, "An Object-Oriented Signal Processing Environment: The Knowledge-Based Signal Processing Package", RLE Technical Report No. 502, Research Laboratory of Electronics, M.I.T., Cambridge, MA, October 1984.

6. Michele Covell and Jae Lim, "Low data-rate video conferencing", SPIE Proceedings, SPIE Vol. 707-Visual Communications and Image Processing, pp. 75-82, September 1986.

7. Susan R. Curtis and Alan V. Oppenheim, "Reconstruction of Multidimensional Signals from Zero Crossings", Journal of the Optical Society of America (JOSA A) Special Issue on Signal Recovery and Synthesis II, Vol. 4, No. 1, pp. 221-231, January 1987.

8. Cory Myers, "Symbolic Representation and Manipulation of Signals", Proceedings, International Conference on Acoustics, Speech, and Signal Processing, Dallas, Texas, April 6-9, 1987, Vol. 4, pp. 2400-2403.

9. Daniel W. Griffin and Jae S. Lim, "Multiband Excitation Vocoder", IEEE Trans. on ASSP, Vol. ASSP-36, No. 8, pp. 1223-1235, August 1988.

Office of Naval Research

DISTRIBUTION LIST

Neil L. Gerr — 4 copies

Code: 1111SP
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217

Administrative Contracting Officer — 1 copy
E19-628
Massachusetts Institute of Technology
Cambridge, MA 02139

Director — 6 copies
Naval Research Laboratory
Washington, DC 20375
Attn: Code 2627

Defense Technical Information Center — 2 copies
Bldg. 5, Cameron Station
Alexandria, VA 22314